

# When Lightning Strikes at Site 300

**L**OCATED 29 kilometers east of Livermore, the Laboratory's Site 300 houses experimental facilities for explosives testing and research. One safety issue affecting operations is the frequent thunderstorms that occur in the Altamont Hills. The staff at Site 300 tracks weather systems in the area, and safety procedures include different levels of lightning alerts, up to and including halting work on explosives and evacuating personnel. Each alert day could reduce the efficiency of the site's operations. To better protect employees and facilities, a team of electrical engineers has developed a certified protection system that eliminates the need for costly work stoppages and building evacuations.

## Flash Facts

Lightning is random, unpredictable, and dangerous. It occurs when rapidly rising air in a thunderstorm interacts with rapidly falling air to create widely separated positive and negative charges within a cloud. The electrical current in a flash averages about 25,000 amperes and can go up to 400,000 amperes. Voltages can be hundreds of millions of volts, and the air ionized by a flash can reach nearly 28,000°C, more than four times the temperature on the surface of the Sun.

In the most common type of cloud-to-ground lightning, negative charges emerge from the bottom of a cloud and create ionized channels, called stepped leaders. The leaders' strong electric field induces streamers of positively charged ions to develop at the tips of grounded pointed objects, such as lightning rods, trees, and blades of grass. The streamers flow upward and join the negatively charged leaders, creating a pathway to the ground. A pulse of current, called a return stroke, travels through the streamer object and up the ionized channel to the charge center within the cloud. Additional negative discharges, called dart leaders, often move down this ionized path, thus forming subsequent return strokes.

## The Explosive Connection

According to the National Lightning Safety Institute, some 2,000 ongoing thunderstorms around the world cause about 100 cloud-to-ground strikes each second. Site 300 averages 50 alert days per year based on data from the last 3 years, and each alert may reduce the efficiency of operations. No strikes to Site 300 facilities have been verified, but lightning has struck nearby power poles and lines and the open ground.



Personnel and facility safety is always the top priority in operational planning at Site 300. In analyzing the work procedures during thunderstorm alerts, Cal Dibble, a project manager in Livermore's Plant Engineering Department, believed the operations could be improved. He proposed to investigate structural improvements at the site and worked with a team of Livermore engineers to develop and certify a lightning protection system.

"In the past, we depended on lightning rods attached to buildings," says Livermore engineer Mike Ong, who researches electrical safety. When used on a wooden structure, lightning rods will guide a current along the path of least resistance—down the metal pole or wire and into the ground. However, lightning rods are not as effective with typical explosives facilities, which have rebar in the walls and ceiling.

Work involving explosives is of particular concern during lightning storms. The safety limit for currents flowing through some detonators is less than 1 ampere, but peak lightning currents may hit tens of thousands of amperes. Therefore, a critical part of the lightning protection system is to separate explosive components from the current-conducting objects and possible arcs from objects in a room.

To do that, the Livermore engineers want each room, or cell, to act like a Faraday cage and shield the components inside the room from lightning strikes outside. In an ideal world of frictionless surfaces and massless springs, the Faraday cage would be a solid metal shell of perfectly conducting metal. If the outside of this ideal cage were struck by lightning, currents and electric fields would be conducted down the outside surface of the shell to the ground, never reaching the shell's interior surface. In the real world, buildings or rooms can only approximate a Faraday cage, and measurable fields and currents will leak inside the structure. Faraday cages prevent internal arcs by minimizing the electric fields within a cage.

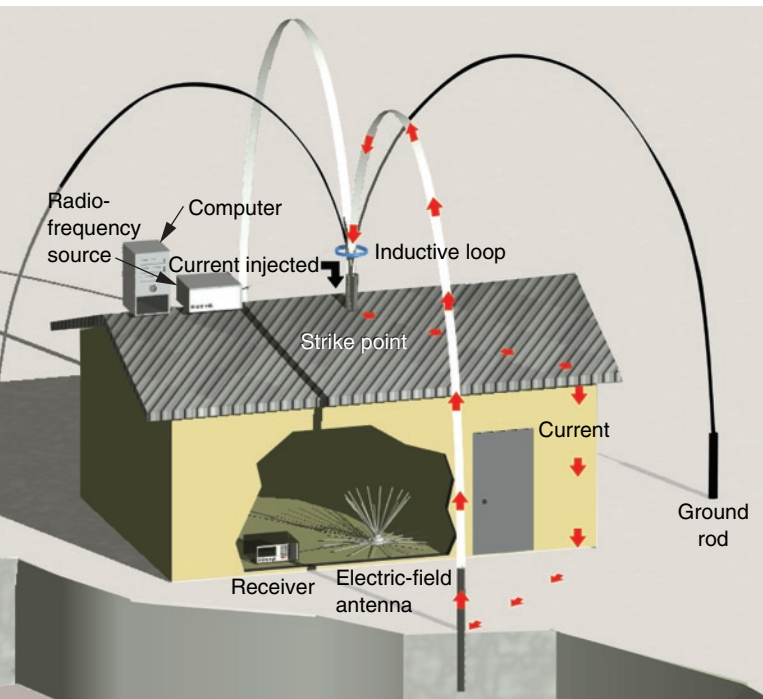
"A car's metal frame approximates a Faraday cage," says Ong, "so being inside a car can be a fairly safe place during a lightning

storm, as long as the person inside stays away from the 'shell' of the car. At Site 300, we want to design rooms so most of the electric fields from a lightning strike will remain outside the building and not penetrate enough to create an arc of current that can reach an explosive."

### Re-creating a Bolt from the Blue

To determine each facility's Faraday-cage effectiveness, Livermore engineer Todd Clancy worked with Dibble and others to measure the conducting capability of each wall in a room. Most buildings at Site 300 are made of concrete reinforced with metal rebar, which provides a pathway for a lightning current to travel to the ground. Moisture absorbed by the concrete also acts as a conductor, drawing current down the wall into ground. The reinforced concrete thus creates a Faraday-cage effect for those buildings.

However, any metal that penetrates a structure's wall, such as a water pipe or phone line, provides an alternate pathway for the currents and fields to enter a building. To retain the integrity of the Faraday cage, electricians bonded these metallic structures to the building's rebar, so that all of the conducting material is interconnected.



For the Site 300 experiments, wires connected grounded rods to likely strike points at the top of the building being tested. Milliampères of current were inductively injected through the strike point and driven through the facility's ceilings and walls to the ground. The current then traveled through the ground rods and back through the wires.

Clancy then conducted experiments to determine the potential currents and electric fields that a lightning strike might generate inside each cell. For these experiments, wires connected likely strike points at the top of a building to metallic rods driven into the ground around the facility. Milliampères of current with a frequency range similar to that of lightning were injected inductively through the strike point. A broadband antenna measured the fields at various points along the wall and in the center of the cell. A probe was used to measure the currents injected at likely strike points.

The current was driven through the facility's ceilings and walls to the ground, and then it traveled through the ground rods and back through the wires. "The voltages produced were generally highest at the ceiling and the top of walls and lowest at the foot of the wall and on the floor," says Clancy.

Team member Charles Brown ran the experimental data through signal-processing calculations to extrapolate the measured currents to lightning-strike proportions. "First, we used experimental data to compute a wall's impedance, which relates the wall's floor-to-ceiling voltage to the injected current," says Brown. "Then using signal-processing techniques, we extrapolated the wall's response to that of a current of lightning-strike proportions and computed the necessary standoff distance."

Even when the standoff distance is doubled to increase the safety margin, it is about 15 centimeters from the wall. Standoff lines are then painted on the floors of each room, and all explosives components must be located inside the painted lines before a building can be certified for lightning protection. "This requirement mitigates the danger of an electrical arc hitting the explosive," Brown says. "Our team is very conservative in determining standoff distances."

### Certification and Staying Safe

According to Clancy, the team has certified most of the appropriate facilities at Site 300, and personnel are being trained. With this certified protection system, the facilities do not have to shut down under threatening conditions, which will save the Laboratory close to \$250,000 a year.

Now, when the thunder rolls, employees at Site 300 can continue their jobs, knowing that they and the explosives inside the buildings are safe from any bolts from the blue.

—Ann Parker

**Key Words:** explosives, Faraday cage, hazard management, lightning, signal processing, Site 300, workplace safety.

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